

TITLE OF THE INVENTION

WIRELESS IMAGING APPARATUS AND ITS CONTROL METHOD

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FIELD OF THE INVENTION

The present invention relates to a wireless imaging apparatus and its control method.

BACKGROUND OF THE INVENTION

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In recent years, wireless communication using radio frequency (RF) and light is widely performed. For example, a cellular phone using a magnetic wave in a 900 to 1900 MHz band is indispensable as an anytime-and-anywhere communicable wireless mobile communication tool. Further, as communication means between personal computers or between a personal computer and a printer, wireless communication using a radio wave in a 2.45 GHz band in conformity with wireless LAN (IEEE 802.11b or IEEE 802.11a) or Bluetooth standard, is realized and widely used in offices and houses. Further, a Suica (registered trademark) card, adopted by East Japan Railway Company in 2001, realizes non-contact reading and writing of ticket at a station ticket gate.

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The above tools are about palm-sized products, however, coin-sized or smaller wireless communication tools, so-called radio tags are used for personal identification (ID) purpose and the like. For example,

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an anti-theft automobile key is realized by using a small radio tag of about 1 cm embedded in the key thereby enabling an authentication operation upon turning-on of the key. In addition, in a case where
5 cable communication cannot be performed without difficulty between e.g. a mountain top place and a point at the ground, optical communication is employed for high-speed communication of images obtained by a camera.

10 Further, a value-added network incorporating a large number of sensors has been actively developed. For example, proposed is a system as a precaution against earthquake, constructed with an acceleration sensor and a strain sensor embedded into a steel frame
15 of a building structure for measuring the degree of fatigue of the steel frame or concrete.

Further, recently, a wireless sensing network is positively proposed.

Nikkei Electronics issued July 15 2002 introduces
20 in pp 99 to 129, several sensing network systems. For example, a large number of sensors are distributed in a forest, and the amount of generated oxygen, the amount of absorbed CO₂, the temperature, humidity of the forest and the like are grasped in detail, for the
25 purpose of early detection of bush fire or CO₂ emission trading.

Further, an imaging network by optical sensing

may be constructed. Among various types of lenses for an imaging system USP 5,004,328 discloses a spherical lens 1 including an aperture 2 in its central portion as shown in Fig. 11. It is known that the aperture
5 improves image formation characteristic of the imaging system.

In a case where a wireless sensing network is constructed by arranging a large number of sensing devices (hereinbelow, each referred to as an "Mote"),
10 to sense a slight environmental change in a wide range, the size of the Mote must be small. Further, in wireless communication, to perform communication with a place as far as possible, the size of antenna must be as large as possible.

15 Accordingly, in a case where a wireless sensing network by wireless communication is constructed for sensing a slight environmental change in a wider range, it is necessary to reduce the size of the Mote and increase the size of the antenna for wireless
20 communication.

However, if the antenna for wireless communication is provided in the Mote, the size of the Mote increases, which disturbs construction of wireless sensing network for excellent sensitivity to
25 environmental change. Further, as the structure of the Mote is complicated, a manufacturing process of the Mote becomes complicated.

Further, upon construction of a sensing network system with distributed devices having sensing and communication functions (hereinbelow, each referred to as a "sensing Mote"), if each sensing Mote has a high performance capability, the cost is increased by
5 arranging a large number of sensing Motes.

Further, in a case where the sensing Mote is reduced in size for sensing a slight environmental change, the sensing function installed in the small
10 sensing Mote is limited.

SUMMARY OF THE INVENTION

The present invention has its object to solve the
15 above-described problems individually or at once, and to simplify the structure of a wireless imaging apparatus without increasing the size of the apparatus.

According to the present invention, the foregoing object is attained by providing a wireless imaging
20 device, comprising: an imaging section, arranged to provide a function of imaging a subject; and a communication section, arranged to provide a wireless communication function, wherein the imaging section comprises an optical lens, an aperture to limit
25 incident light on the optical lens, an optical sensor to convert the incident light passed through the aperture into an electric signal, and an antenna

integrally provided with the aperture, to wireless-transmit the electric signal converted into a radio signal by the communication section.

Further, the foregoing object is attained by
5 providing an image obtaining apparatus, comprising a plurality of the above devices, wherein the plurality of devices and the wireless communication construct a network of the plural devices.

Further, another object of the present invention
10 is to simplify to functions of each wireless imaging apparatus and to provide a high-level imaging function by realizing co-operative work by plural wireless imaging apparatuses.

According to the present invention, the foregoing
15 object is attained by providing an image obtaining apparatus, comprising a plurality of imaging devices which provide a wireless communication function and a single imaging function, wherein the plurality of imaging devices provide, as a whole, one or more high-
20 level imaging functions by co-operative work using the wireless communication function.

Other features and advantages of the present invention will be apparent from the following description taken in conjunction with the accompanying
25 drawings, in which like reference characters designate the same name or similar parts throughout the figures thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

Figs. 1 and 2 are schematic diagrams showing a wireless imaging device included in a wireless imaging apparatus according to a first embodiment of the present invention;

Figs. 3 to 5 are schematic diagrams showing an aperture of the wireless imaging device;

Figs. 6 and 7 are explanatory views showing a manufacturing method of the wireless imaging device;

Fig. 8 is a schematic diagram showing the wireless imaging device included in the wireless imaging apparatus;

Figs. 9 and 10 are explanatory views showing the wireless imaging apparatus according to a second embodiment of the present invention;

Fig. 11 is a schematic diagram showing a spherical lens;

Fig. 12 is a schematic diagram showing the construction of a wireless communication apparatus according to a third embodiment of the present invention;

Fig. 13 is a schematic diagram showing the structure of an imaging Mote according to the third embodiment;

5 Figs. 14 to 17 are schematic diagrams showing the structure of the imaging Mote according to a fourth embodiment of the present invention;

Figs. 18A and 18B are schematic diagrams showing positional relation between the spherical lens of the imaging Mote and the aperture according to a fifth
10 embodiment of the present invention;

Figs. 19A to 19C are schematic diagrams showing an example of aperture sizes of the imaging Mote according to a sixth embodiment of the present invention;

15 Fig. 20 is a schematic diagram showing the structure of color filters of the imaging Mote according to a seventh embodiment of the present invention;

Fig. 21 is a schematic diagram showing an example
20 of lens refractivities of the imaging Mote according to an eighth embodiment of the present invention;

Figs. 22A to 22C are schematic diagrams showing an example of a junction position between the spherical lens and an optical sensor; and

25 Fig. 23 is a schematic diagram showing an example of an imaging network system according to a ninth embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of a wireless imaging
5 apparatus of the present invention will be described in
detail in accordance with the accompanying drawings.

<First Embodiment>

[Structure of Wireless Imaging Device in Wireless
Imaging Apparatus]

10 Fig. 1 is a schematic diagram showing a wireless
imaging device (imaging Mote) 100 included in the
wireless imaging apparatus according to a first
embodiment of the present invention.

The imaging Mote 100 has a spherical lens 1, an
15 aperture 2 provided in a position of overlapped bottom
parts of imaginary 2 hemispherical members divided from
the center of the spherical lens 1, to limit incident
light in the imaging Mote 100, a coil antenna 3
integrally provided with the aperture 2, and an optical
20 sensor 4 to convert the incident light passed through
the aperture 2 into an electric signal in a position
around a vertical point on the inner side of one
hemispherical member. Further, a wireless
communication circuit 4a, to generate a high frequency
25 signal from image data converted into the electric
signal by the optical sensor 4, is provided on the same
substrate of the optical sensor.

The coil antenna 3 has a terminal (not shown) electrically connected to the wireless communication circuit 4a, to transmit the high frequency signal generated by the wireless communication circuit 4a to
5 the outside via the antenna 3.

Fig. 2 illustrates a case where the substrate holding the optical sensor 4 and the wireless communication circuit 4a is provided separately from the spherical lens 1. In this case, the aperture 2 has
10 the coil antenna 3. In comparison with Fig. 1, the antenna 3 or a light-emitting device for optical communication can be provided on the rear side of the substrate in Fig. 2. Note that when the imaging Mote 100 is constructed, it is preferable that the optical
15 sensor 4 is provided on the inner spherical surface of the spherical lens 1 as shown in Fig. 1.

Figs. 3 to 5 show other examples of the antenna 3 in Figs. 1 and 2.

Fig. 3 shows a coil 31 of the antenna 3, having
20 an about 3 turns, for higher communication performance.

Fig. 4 shows the antenna 3 having approximately the same structure as that in Fig. 1. The coil of the antenna 3, having the same 1 turn, is arranged on the outer peripheral side of the aperture 2, for
25 improvement in communication performance.

Fig. 5 shows an arrangement where the entire surface of the aperture 2 functions as an antenna 23.

In this case, the area of the aperture 2 can be most effectively utilized. However, the antenna 23 must be formed of a high-conductivity material as a high-performance antenna.

5 In the present invention, if the imaging Mote 100 has a diameter of 1 mm, the maximum diameter of the coil of the antenna 3 is 1 mm.

 Further, the present invention includes, in its scope, management of image information by a sensing
10 network system constructed with functional device group of plural imaging Motes 100 to perform imaging functions by co-operative work using wireless communication.

15 [Manufacturing of Wireless Imaging Device]

 Next, a manufacturing method of the imaging Mote 100 according to the present embodiment will be described.

 Fig. 6 is an explanatory view showing the
20 manufacturing method of the imaging Mote 100 according to the present embodiment. First, hemispherical resin mold lenses 20 are formed by using a metal mold 50 having plural hemispherical cavities 21 as shown in Fig. 6.

25 Next, two of the hemispherical lenses 20 are joined with the aperture 2 therebetween as shown in Fig. 7. At this time, the aperture 2 is already provided

with the antenna 3. Upon completion of the joining, the substrate holding the optical sensor 4 and the communication circuit 4a, and the antenna 3 are electrically connected via wires 60.

5 Through the above process, the imaging Mote 100 of the present embodiment provided with the aperture 2 and the antenna 3 is completed. Further, by the above manufacturing method, a large number of imaging Motes 100 can be formed at once.

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<Second Embodiment>

Fig. 9 is an explanatory view showing the wireless imaging apparatus where plural small spherical imaging Motes 100 are provided on a card substrate 42.

15 The wireless imaging apparatus of the present embodiment has a base 41, to communicate with the plural imaging Motes 100 and control the imaging Motes 100, on the substrate 42.

20 The wireless imaging apparatus shown in Fig. 9 has the imaging Motes 100 to receive light 43 from a subject, generate sensing image information from the light and transmit the information via the antenna 3 integrally formed with the internal aperture 2 to the outside, and the base 41, provided on the card
25 substrate 42, to receive the sensing image information from the imaging Motes 100. The base 41 performs high image quality processing based on the image information

received from the plural imaging Motes 100, and
processing for obtaining 3-dimensional image
information by calculation of depth information
utilizing a parallax error between the small spherical
5 imaging Motes 100.

Fig. 10 is an explanatory view showing another
example of the wireless imaging apparatus where the
plural small spherical imaging Motes 100 are provided
along various directional optical axes so as to obtain
10 a wide angle of image information. As in the case of
the wireless imaging apparatus in Fig. 9, the wireless
imaging apparatus in Fig. 10 has the imaging Motes 100
to receive light 43a to 43f from the respective
directions, generate sensing image information from the
15 light and transmit the information via the antenna 3
integrally formed with the internal aperture 2 to the
outside, and the base 41 to receive the sensing image
information from the imaging Motes 100, combining the
information from the respective directions and generate
20 wide-angle image information.

Although not shown, the base 41 has a function of
transmitting a control signal to turn on/off a
transmission operation of sensing image information of
the wireless communication circuit 4a of each imaging
25 Mote 100. The base can sequentially obtain image
information by scanning the plural imaging Motes 100 by
on-controlling the transmission operations in desired

imaging Motes 100. Otherwise, it may be arranged such that the base 41 has a control function of on/off controlling power supply to the wireless communication circuit 4a of each imaging Mote 100, and sequentially
5 obtains the image information by scanning the plural imaging Motes 100 by on-controlling the power supply to the wireless communication circuits 4a of desired imaging Motes 100. Otherwise, it may be arranged such that frequencies of radio signals emitted from the
10 plural imaging Motes 100 are different, and image information is sequentially obtained from the plural imaging Motes 100 by scanning reception frequencies by the base 41.

According to the above-described embodiment, as
15 the antenna 3 for wireless communication is integrally formed with the aperture 2, a predetermined size of the antenna 3 can be ensured without increasing the wireless imaging device in size, and a wireless imaging apparatus having excellent sensing sensitivity to an
20 environmental change can be realized. In comparison with the case where the antenna is provided separately from the aperture 2, the structure of the imaging device can be simplified and the manufacturing process can be facilitated.

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<Third Embodiment>

Fig. 12 is a schematic diagram showing the

construction of a wireless communication apparatus according to the present invention. The wireless communication apparatus has plural functional devices (imaging Motes 1) having a wireless communication
5 function and an imaging function as a functional device group.

In Fig. 12, the imaging Motes 1a to 1j are provided at random in random directions. As shown in Fig. 13, the imaging Mote 1 performs imaging by
10 gathering light 113 incident on a spherical lens 111 by an optical sensor 112. The obtained image information is wireless-transmitted using e.g. an electromagnetic wave 120, to a base 10. That is, the optical sensor 112 as shown in Fig. 13 includes a wireless
15 communication unit (not shown).

For example, in Fig. 12 where imaging is performed on a subject 15, video images obtained by the imaging Motes 1a, 1c, 1e and 1i directed to the subject 15 are combined by the base 10.

20 In the present embodiment, the respective imaging Motes 1 have a simple structure where the aperture and the lens position are fixed. That is, a general camera has mechanisms to change the depth of subject with a variable aperture and move the lens position to adjust
25 focus of the lens, whereas the imaging Mote 1 of the present embodiment has a single imaging function without variable part, i.e., the structure is

simplified with the respective fixed parts.

Accordingly, as reduction of cost and electric power consumption can be realized in each imaging Mote 1, even if a sensing network is constructed with a large number of imaging Motes 1, the entire electric power consumption and cost are not increased.

Further, as imaging is performed by the large number of imaging Motes 1, the subject can be image-sensed from various angles, and the dynamic range of aperture, focus, sensitivity and the like can be widened. That is, although each imaging Mote 1 has a simple structure, when a large number of imaging Motes 1 function as a group, the group functions as a high-performance imaging device.

Note that in the above description, the electromagnetic wave 120 is used in wireless communication, however, optical communication may be used in the wireless communication. Further, as described in the subsequent embodiment, in addition to omission of movable parts, the imaging Mote 1 can be simplified by employing any one of R, G and B color filters as a single filter.

Further, the base 10 may have the same structure as that of other imaging Motes 1. In this case, the wireless communication apparatus does not have an imaging Mote named "base", but one of the imaging Motes 1 is connected to a network circuit thereby

communication with the outside is performed. Note that
in a case where images obtained by the respective
imaging Motes 1 are corrected and combined into one
image prior to communication with the external network
5 line, it is preferable that the base 10 is separately
provided from the imaging Motes 1 as in the case of the
above description.

<Fourth Embodiment>

10 Fig. 14 is a schematic diagram showing the
structure of the imaging Mote according to a fourth
embodiment of the present invention.

As an imaging Mote 34, a small spherical lens 31
is employed, an optical sensor 32 for imaging is
15 arranged around the surface of the spherical lens on
the opposite side to the imaging light incident side,
and further, a communication circuit 33 to receive a
radio wave and transmit a signal from the optical
sensor 32 is provided on the same substrate of the
20 sensor around the surface of the spherical lens. In
this case, the substrate has a spherical shape.

Light 36 incident in parallel to an optical axis
35 is condensed by the small spherical lens 31 in a
point 37 around the surface of the lens. Light 38 with
a field angle is condensed by the small spherical lens
25 31 on a point 39 around the surface of the lens. In
this manner, images are formed on the surfaces of the

small spherical lenses. Assuming that the refractive index n_d of the small spherical lens 31 is "2", collimated light i.e. light at infinity is image-focused around the surface of the lens on the opposite side to the incident side. For example, if a glass material S-LAH 70 (Ohara) is used for a visible d ray (587.6 nm), as $n_d = 2.003$ holds, this condition is satisfied. Further, if the diameter of the lens is 1 mm, a focused state can be obtained beyond 5 cm.

Although a sufficient image can be obtained since a chromatic aberration is not so large, the surface of the spherical lens 31 on the incident side is provided with a filter for selection of particular wavelength, thereby the chromatic aberration can be suppressed.

Further, 100×100 (for 10,000 pixels) photoreception devices, having 1-cell diameter of $2 \mu\text{m}$, can be provided. As the photoreception devices are provided in a small sphere, a stable functional device unsusceptible to external environment can be obtained.

Fig. 15 shows the small spherical lens 31 having a flat surface on the side of the optical sensor 32 of the sensing Mote 34. As the optical sensor 32 has a flat shape, the aberration is increased, however, the circuit can be easily formed on the flat substrate.

This structure is available in an application in which image quality is not so important. Further, as a manufacturing method, the small spherical lens 31 is

formed, then the imaging side is ground to a flat surface, and a separately-formed flat substrate is joined to the flat surface. In this manner, the lens can be easily manufactured. That is, the optical
5 sensor 32, the communication circuit 33 and the like are formed in advance on the flat substrate, thereafter, the substrate is joined to the small spherical lens 31 by adhesive bonding or the like. Further, a light emitting device for optical communication may be
10 provided on the substrate.

Further, in this arrangement, the refractive index of the small spherical lens 31 is not necessarily set to "2", but the thickness of the flat substrate is set for image formation on the imaging surface. As the
15 glass material, LaSFN9 ($n_d = 1.850$), sapphire, ruby, Al_2O_3 ($n_d = 1.77$) and the like may be used as glass material appropriate to purposes under sever conditions (transmission with high intensity, high hardness, anti-chemical property, IR transmission). Otherwise, a very
20 low-price sensing Mote 34 can be manufactured using general glass material, BK7 ($n_d = 1.517$).

Fig. 16 shows an example where, different from the above case where the circuit system is directly formed on the surface of the small spherical lens 31, a
25 separately-formed substrate 30, holding electronic circuits such as the optical sensor 32 and the communication circuit 33, in contact with the small

spherical lens 31, is joined with the lens using adhesive 54 or the like. In this case, the adhesive 54 constructs a part of the lens system. Influence of aberration increases as the field angle is shifted from the optical axis, however, in some purposes, the image information can be utilized as high resolution image is not required. In this manufacturing, a very low-price sensing Mote 34 can be formed and used for a wide range of purposes.

10 Fig. 17 shows an example where, different from the above-described spherical lens, the imaging Mote has an optical lens 6 which is a general convex lens. Incident light is passed through an aperture 7 and is gathered on an optical sensor 8, and delivered as data
15 by wireless communication from a communication circuit 9.

Generally, various types of lenses are designed for a wide field angle imaging optical system. In the optical system of this type, as the lens diameter
20 increases, the image screen size increases, which increases the size of the imaging optical system. Further, in a case where wide field angle sensing is intended in a conventional optical system, the amount of ambient light is greatly reduced due to the well-
25 known cosine fourth power law.

As a simple optical system to attain a wide field angle, a spherical lens is conventionally known.

Generally, in a lens system having a small curvature and a flat image surface, the size of image surface is infinitely increased as the field angle becomes closer to 180° , and the amount of ambient light reaches to the
5 image surface is greatly reduced. Accordingly, in a conventional fish-eye lens, a large negative curvature aberration is intentionally caused, to attain the 180° field angle and prevent the significant reduction of amount of ambient light. However, as the occurrence of
10 negative curvature aberration equals compression of image in a peripheral portion of the image surface, the resolution is lowered and the image formation performance is degraded.

On the other hand, in a case where the image of a
15 subject at infinity is focused using a spherical lens, the image surface is a spherical surface cocentric with the spherical lens due to spherical symmetric property of the lens. Accordingly, in the spherical lens, axial aberration and off-axial aberration are equal. If
20 approximately excellent aberration correction is attained on the axis, the off-axial aberration can be similarly corrected.

Further, if a sensor having a spherical photo reception surface is provided on the spherical image
25 surface, excellent imaging can be performed at nearly 180° wide field angle.

More particularly, assuming that the focal

distance of the spherical lens is f , if the photoreception area of the sensor is $2\pi f^2$, a field angle of 180° can be obtained. Thus a small sensor can be used. Further, the degradation of resolution in a lens peripheral portion due to spherical symmetric property of the spherical lens does not occur. Further, the great reduction of the amount of ambient light due to the cosine forth-power law in a general lens system does not occur. The amount of ambient light is merely reduced in proportion to the power of the cosine of incident angle.

Accordingly, in this optical system which is smaller and simple in comparison with a general lens system, as reduction of the amount of ambient light is small by appropriate aberration correction, a wide field angle optical system with an entirely bright image surface and excellent image forming performance can be obtained.

To provide a large number of imaging Motes and to obtain a fine image, the downsizing of the imaging Mote is important. For this purpose, it is preferable that the imaging Mote is constructed with a spherical lens and an optical sensor.

25 <Fifth Embodiment>

The imaging Mote using a spherical lens has been described in the forth embodiment. As shown in Fig.

18A, the aperture 77 is positioned on the incident light side of the spherical lens 66 or positioned inside the spherical lens 66 as shown in Fig. 18B. If the aperture 77 is positioned in the central portion of the spherical lens 66, a high resolution image can be obtained, the field angle can be increased, and unnecessary light can be eliminated by reduction of coma aberration. Accordingly, more preferably, the aperture 77 is positioned in the central portion of the spherical lens 66.

If the aperture 77 is reduced in size, as the aberration of the lens is suppressed, degradation of image due to the aberration is reduced, and the resolution is improved. In contrast, if the aberration is small, the relation among the resolution R , the wavelength λ , the lens numerical aperture NA , the lens refractive index n , and the aperture (lens effective aperture) D is as follows.

$$\begin{aligned}
 R &= k | (\lambda/NA) = k | (\lambda/n \sin\theta) \approx k | (\lambda/n \tan\theta) \\
 &= k | [\lambda/n \{(D/2)/L\}] = k | [2\lambda/(nD/L)] = k | (2\lambda/Fno)
 \end{aligned}$$

That is, as the aperture D increases, the resolution R is improved in proportion to the aperture.

On a wavelength of 400 nm to 900 nm, as the numerical aperture of several hundred μm is sufficiently large, the above concept is applied. The

focal depth DOF is $k_2\{\lambda/(NA)^2\}$, and becomes shorter in
proportional to the second power of the aperture D. In
the spherical lens, as the influence of the aberration
is greater, high resolution and long depth can be
5 attained when the aperture is small.

<Sixth Embodiment>

Figs. 19A to 19C are schematic diagrams showing
examples of the imaging Mote. The imaging Mote,
10 constructed with the spherical lens 66 and the aperture
77, has different apertures as shown in Figs. 19A to
19C. A large number of imaging Motes having different
apertures are provided, and video image data obtained
from the respective imaging Motes are transmitted to
15 the base. The base selects only a video image from an
imaging Mote having the aperture corresponding to an
imaging subject and imaging environment and uses the
selected video image. Thus the same advantage as that
obtained by changing the aperture in a single imaging
20 Mote can be obtained.

The aperture of the camera is normally changed in
accordance with an imaging subject, a working distance
between the lens and the subject, an imaging
environment such as brightness. However, in the above
25 case, imaging Motes respectively set to several
apertures are provided and imaging data is selected in
correspondence with the circumstance, thus the aperture

can be substantially changed.

<Seventh Embodiment>

In the sixth embodiment, the aperture is changed
5 by selection of imaging Mote. Further, the filter of
the optical lens can be changed by selection of imaging
Mote.

As an example, as schematically shown in Fig. 20,
filters of red (R), blue (B) and green (G) as the 3
10 primary colors of color image may be provided. Any of
the 3 color filters of a CCD sensor may be fixed to
each imaging Mote. Otherwise, even in a case where a
color optical sensor is not used, if each imaging Mote
is constructed with a monochrome optical sensor and a
15 spherical lens with a color-filter, each Mote can
output an image of one of the respective colors.

Further, a filter of any one of cyan, magenta,
yellow and green complementary colors may be employed.

Further, a polarizing filter may be provided.
20 For example, a linear polarization or circular
polarization filter may be set in the respective
imaging Motes, or a combination of these filters with
an infrared filter may be used. The imaging Mote with
a particular polarizing filter is effectively used upon
25 imaging of a subsurface fish or the like.

<Eighth Embodiment>

Fig. 21 is a schematic diagram showing an example where the refractive index n of the spherical lens is slightly changed in respective imaging Motes. A focused state can be obtained in different points in the respective imaging Motes. For focusing at infinity, the point is on the spherical surface with the refractive index $n_d = 2$, however, to get a near subject into focus, the refractive index must be greater than 2. Further, as schematically shown in Figs. 22A to 22C, in a system where the small lens 66 and the substrate 30 as shown in Fig. 16 are joined, if imaging surfaces are arbitrarily defocused, a focused state can be obtained by any imaging Mote.

Note that in the fourth to eighth embodiments, the examples of the spherical lens have been described, however, the present invention is not limited to the spherical lens, but is applicable to imaging Motes using a concave lens, a convex lens and the like.

20 <Ninth Embodiment>

To improve the resolution, images are obtained from a large number of imaging Motes and subjected to image processing, by previously controlling the positions and directions of the respective imaging Motes, or obtaining a mean from a large number of imaging Motes provided at random. In the third embodiment, the imaging Motes are provided at random,

however, as shown in Fig. 23, if the directions of the imaging Motes 1 are controlled to set the lenses toward the imaging subject 15, the number of effective image data is increased. Further, it is more preferable that the positions of the imaging Motes 1 can be controlled. Note that it is necessary to install a direction control mechanism and/or a moving means into the imaging Mote 1.

According to the third to ninth embodiments, as each functional device has a simple structure, low electric consumption and low cost imaging apparatus can be realized, and a high-level imaging network can be constructed.

As many apparently widely different embodiments of the present invention can be made without departing from the spirit and scope thereof, it is to be understood that the invention is not limited to the specific embodiments thereof except as defined in the appended claims.

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